

Physics 180

Nuclear Weapons, Nuclear War, and Arms Control

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Midterm Examination

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Name _____

ID No. _____

- This is a closed book examination of 50 minutes duration.
- Answer all 5 questions. All count equally (20 points each).
- Write your answers in the space provided on these pages. If you need more room, write on the back of the page. For full credit on definitions, give numbers where appropriate.

SCORES

1. 20

2. 20

3. 20

4. 20

5. 20

TOTAL 100

1. Nuclear physics

Define 'fissionable nuclide' and name two. [5 points]

A fissionable nuclide can be caused to split apart (fission) by a neutron. All fissile nuclides are fissionable, by definition (for three examples, see the answer to the next part of the question). Two fissionable but non-fissile nuclides relevant to the course are U-238 and Th-232.

Define 'fissile nuclide' and name two. [5 points]

A fissile nuclide has some probability of being fissioned by a neutron of any energy. [A non-fissile but fissionable nuclide can only be caused to fission by neutrons with energies above the fission threshold energy.] Three fissile nuclides relevant to the course are U-233, U-235, and Pu-239.

Define 'critical mass'. What is the critical mass of a bare sphere of 100% Pu-239? About how large would a sphere of Pu-239 with this mass be? [5 points]

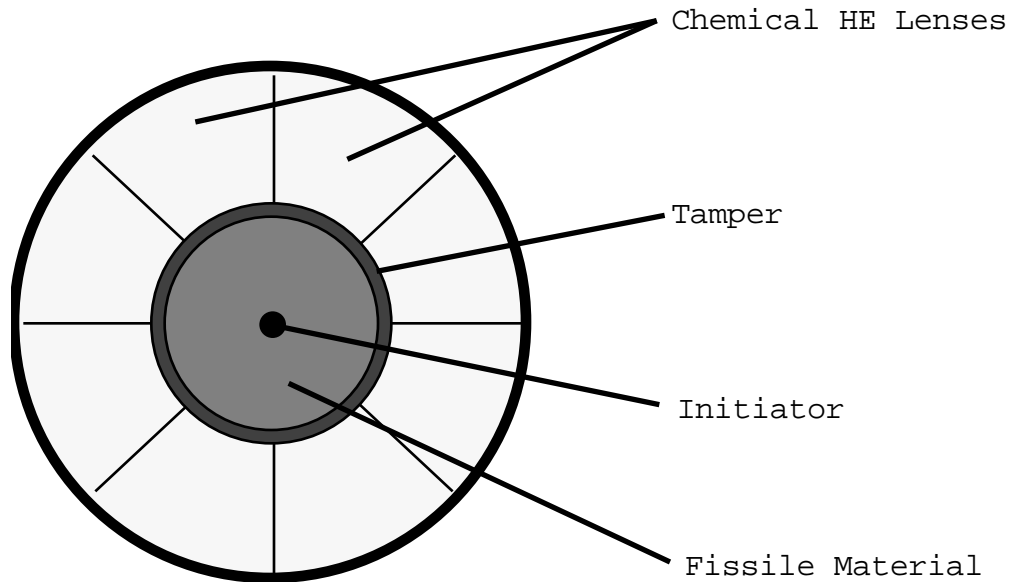
A critical mass is the smallest mass of an element that can sustain a chain reaction. The critical mass of a bare sphere of Pu-239 is about 10 kg (22 lb). Such a sphere is 5.2 cm in radius, or about the size of a baseball.

What is the difference between reactor-grade and weapon-grade plutonium? Can a weapon made of reactor-grade plutonium be made to explode? [5 points]

Reactor-grade [high burn-up] plutonium contains more of the isotopes Pu-240, Pu-241, and Pu-242 than does weapon-grade plutonium. [Full credit given for citing Pu-240 alone.]
Yes, reactor-grade plutonium can be made to explode.

2. Fission Weapons

- a) Shown here is a schematic diagram of an unboosted, implosion-type fission weapon. Indicate on the diagram the locations of the following key components:
- Initiator
 - Chemical high explosive lenses
 - Weapon-grade fissile material
 - Tamper
- [8 points]



- b) Describe briefly the roles of each of these four components. [12 points]

Initiator: Provides neutrons at the instant of maximum compression to assure that the chain reaction will be initiated then.

Chemical high explosive lenses: Create a focused shock wave that compresses the fissile material, causing it to go critical.

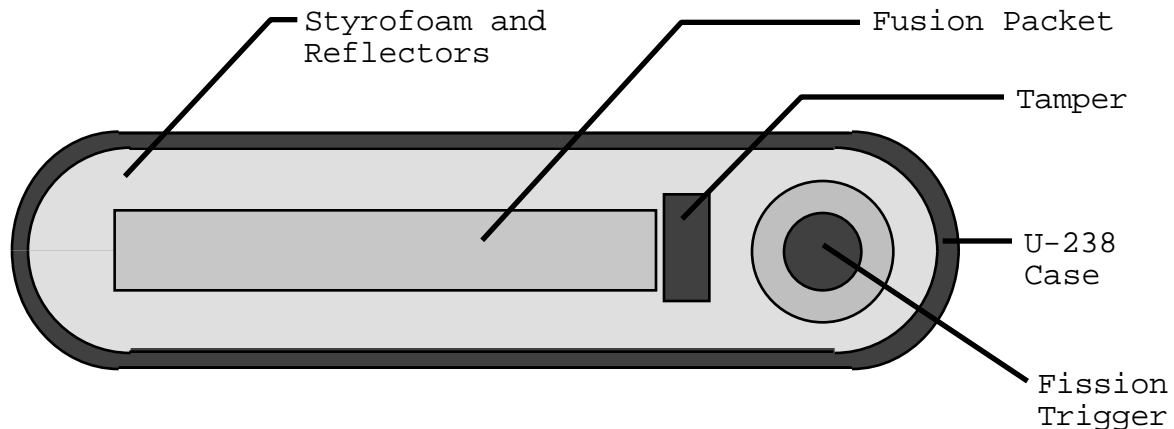
Weapon-grade fissile material: Provides energy and further neutrons when fission reaction is started by the initiator. The nuclear 'fuel' of the weapon.

Tamper: Reflects neutrons back into the fissile material and helps (by its inertia) to keep the fissile material together, thus increasing the percentage of the material that fissions.

3. Thermonuclear Weapons

a) Shown here is a schematic diagram of a standard thermonuclear weapon. Indicate on the diagram the locations of the following key components:

- ${}^6\text{LiD}$ fusion packet
 - U-238 case
 - Fission trigger
 - Tamper
 - Styrofoam and reflectors
- [10 points]



b) Describe briefly the roles of each of these five components. [10 points]

${}^6\text{LiD}$ fusion packet: The thermonuclear 'fuel' of the weapon. When exposed to neutrons, the ${}^6\text{Li}$ acts as a 'catalyst', providing more neutrons and and tritium to fuse with the deuterium (D), releasing energy.

U-238 case: Has two purposes: holds the weapon together, increasing the yield of the fusion packet; fissions when exposed to the intense neutron flux from the fusion reactions, adding to the fission yield of the weapon.

Fission trigger: Provides the X- and γ -rays that compress and heat the fusion packet, causing the thermonuclear reaction to go.

Tamper: Slows propagation of the debris and shock wave from the fission trigger into the fusion packet, allowing the fusion reaction to proceed for some time before the fusion packet is disrupted.

Styrofoam and reflectors: Styrofoam holds the fusion packet in place and, when exposed to the X- and γ -rays from the fission trigger, creates a high-pressure plasma that helps to compress the fusion packet. Reflectors direct X- and γ -rays onto the surface of the fusion packet.

4. Weapon Effects I

a) Give brief (one- or two-sentence) definitions of the following terms. [12 points]

- **Air burst**—A burst in which the fireball does not touch the ground.
- **Slant range**—The straight-line distance from the center of an air burst to the target (the target is usually assumed to be on the ground).
- **Firestorm**—An intense, large-scale fire in which the winds created by the updraft of the heated air become so strong that the fire is concentrated in a central area and is fed by fuel sucked into the central area. [In contrast, a *conflagration* is an intense, large-scale fire with a burning front that gradually expands, leaving behind the burned fuel.]
- **Electromagnetic pulse (EMP)**—The short pulse of electromagnetic radiation produced by nuclear explosions of all types, but especially explosions near the ground or at high altitudes. The EMP typically lasts $\sim 10^{-8}$ – 10^{-9} sec and may produce large currents and high voltages that severely damage electrical or electronic equipment. [EMP is generated by the asymmetry of the explosion, which can produce large, rapidly-varying electrical currents. The strongest electrical fields are produced by explosions at or near the earth's surface, but high-altitude explosions may produce damaging fields over a much larger area. For example, a megaton-size explosion at 200 miles above Omaha, Nebraska, would produce potentially damaging EMP over the whole continental United States, as well as parts of Mexico and Canada.]
- **Ground zero**—For an airburst, the point on the ground vertically below the center of the explosion. [For an underground burst, the point vertically above the center of the explosion.]
- **Fireball**—The rapidly expanding, very hot region of heated air and vaporized weapon debris in which the X and UV radiation from the burst is initially trapped.

b) In what order would the following effects be experienced by a person located 3 miles from the center of a 1 Mt airburst produced by a thermonuclear weapon? Give a brief explanation of each effect. [8 points]

- **Fallout** [4th]—The radioactive dust that is produced when the fireball touches the ground and radioactive vapor condenses on dust and soot. These particles are carried upward by the mushroom cloud and then fall down or are washed down, forming a coating of radioactive dust over the ground, structures, and people.
- **Thermal pulse** [2nd]—The pulse of heat (infrared) radiation produced within the first few seconds after a nuclear explosion as the radiating surface of the fireball expands and temperature of the fireball falls.
- **Blast wave** [3rd]—The very strong sound wave that breaks away from the expanding fireball and races outward, producing a sudden compression followed by a strong outward wind and then a weaker inward wind.
- **Prompt nuclear radiation** [1st]—The nuclear radiation produced during the fission and fusion reactions that take place in the nuclear weapon.

5. Weapon Effects II

a) Give brief (one- or two-sentence) definitions of the following terms. [12 points]

- **Ionizing radiation**—Radiation (UV, X-rays, and γ -rays) that is energetic enough to strip electrons from atoms and molecules.
- **Physical dose**—The energy deposited in the target tissue or material by the incident radiation. Measured in rads.
- **Relative biological effectiveness (RBE)**—The factor that describes the relative effectiveness of the particular type of radiation in causing the type of biological damage of interest; converts a dose in rads into a dose in rems.
- **Chronic exposure**—Exposure to radiation lasting more than 24 hours. [To be distinguished from acute exposure, which is exposure lasting less than 24 hours.]
- **Half-life**—The time after which there is a 50% probability that a given radionuclide has decayed. [For a macroscopic quantity of a given radionuclide, the time after which the amount still remaining has fallen to half the original amount. Note that the half-life can be defined only for a *single* radionuclide, since a mixture of radionuclides will have a mixture of half-lives.]
- **Neutron bomb**—Technically called an *enhanced radiation weapon* (ERW), a "neutron bomb" is a thermonuclear nuclear weapon that has been designed to increase as much as possible the total number of neutrons produced when it explodes while decreasing as much as possible the strength of the blast. [This is done by minimizing the amount of material in the fission trigger and eliminating material, such as the fission blanket that is present in a "conventional" three-stage thermonuclear weapon, that would absorb neutrons, while increasing the relative amount of the fusion fuel.]

b) Answer briefly the following questions about *nuclear winter*. [8 points]

- Explain qualitatively what causes the effect called nuclear winter and how nuclear weapons may produce it. [3 points]

Fires ignited by nuclear explosions create soot, which is lofted into the stratosphere. The soot reduces the amount of solar energy that reaches the earth's surface and hence the temperature in the atmosphere below the stratosphere falls. The stability of the stratosphere and the lack of 'weather' there allow the soot to remain airborne for a long time (months to years).

- Three-dimensional (3D) calculations were found to give results *quantitatively different* from one-dimensional (1D) calculations. Describe the key differences. [2 points]

The temperature is reduced less, and for a shorter period of time. Freezing is not prevalent, making the result more of a "nuclear fall" than a "nuclear winter".

- List two important features or processes that cannot be included in 1D calculations but can be included in 3D calculations. Explain their importance. [3 points]

(1) Differences between land and ocean. The temperature of most interest is the temperature over land, where people live and crops are grown, but most of the earth's surface is ocean. Oceans retain much greater amounts of heat than land, ameliorating the effects of lack of sunlight.

(2) Spreading of smoke in E-W and N-S directions, effects of winds and weather, including 'washout' of smoke. Smoke may take some time to spread over a whole continent, so that its effects are localized for some time. Winds may cause smoke to cover some areas but not others. Rains, including rains triggered by the smoke, may wash some of it out of the troposphere before it reaches high altitudes, where it would remain for a much longer time..

(3) Transport between the Northern and Southern hemispheres. This transport may take months, or may not ever be significant, in which case the areas not covered by smoke will not be directly affected.

